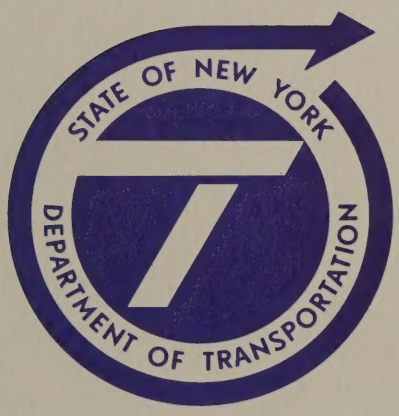
ENGINEERING RESEARCH AND DEVELOPMENT

The First Ten Years



The Engineering Research and Development Bureau conducts and administers New York's engineering research program, in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. The Federal Government provides financial assistance for this program through Highway Planning and Research Funds. This publication's contents reflect the opinions, findings, and conclusions of the New York State Department of Transportation, and not necessarily those of the Bureau of Public Roads.

ENGINEERING RESEARCH AND DEVELOPMENT: THE FIRST TEN YEARS

December 1969

ENGINEERING RESEARCH AND DEVELOPMENT BUREAU
New York State Department of Transportation
State Campus, Albany, New York 12226

ABOUT THIS PUBLICATION

A tenth anniversary seems an especially appropriate occasion for an agency's staff to examine its programs. This publication represents an effort by the engineers of this Bureau to determine where we have been, what we have accomplished, and how effectively we have done it. By this review of progress and accomplishments, we believe that we have moved closer to realistic criteria concerning optimum levels of research funding and activity.

The discussion is presented in three parts:

1. Introductory notes on the growth of the Engineering Research and Development Bureau, and its functions in relation to Department goals.

2. A review of past and current programs in terms of research accomplishments in four general categories: increased safety, assured quality of materials, improved design and construction, and assistance in operation and maintenance.

3. A brief look at research benefits to the Department in relation to investment, and at a few particularly important developments in the Bureau's immediate future.

Research results are of only academic value unless implemented. An essential link, then, in the research chain is the transition from research findings to improvements in materials, design, construction, or maintenance as adopted by the Department. For this to take place quickly and smoothly requires not only a problem-oriented research staff with considerable experience in transportation technology, but also open-minded, forward-looking administrators responsible for the final decisions on recommended changes. Our Department has been fortunate, indeed, in having a top-level staff willing to make changes that research has indicated to be beneficial. In particular, B. A. Lefeve, Chief Engineer (formerly Deputy Chief Engineer, Highways) and G. W. McAlpin, Deputy Chief Engineer, Technical Services, have been invaluable to the research program over the years by their encouragement, support, and eagerness to accept sound technical innovations.

New York State's research program is carried out almost exclusively in cooperation with the Bureau of Public Roads and is financed with Highway Planning and Research Funds. As part of this cooperative arrangement, they have provided considerable technical assistance

through their review of proposed experiments and the results of our research. Discussions with their highly competent technical staff were particularly helpful during the early years of our existence.

Malcolm D. Graham

Malcolm D. Graham, Director
Engineering Research and Development Bureau

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I. INTRODUCTION

A. Origin and Growth of the Bureau

In 1958, recognizing the advantages of a formalized research program for the New York State Department of Public Works, George W. McAlpin, Deputy Chief Engineer (Technical Services), proposed the establishment of a physical research unit. A unique aspect of his proposal was that the unit's personnel would have no responsibilities other than full-time research. Thus, pressures of the state's enormous highway design and construction program would not force postponement of vital research investigations, an arrangement that has proved over the years to be a key factor in the research program's success.

The organization resulting from his efforts consisted of 34 engineers and technicians, which together with the Materials and Soil Mechanics Bureaus formed the Technical Services Subdivision. As its limited size and close relationship with these two Bureaus might suggest, essentially the entire program of research then dealt with problems of such engineering materials as aggregates, cements, asphalts, soils, joint sealers, and concrete curing compounds, and with field evaluation of new materials continually being promoted by industry for use on state highway projects.

The research unit's proved competence in solving some long-standing Department problems led to requests from other divisions for research in such fields as pavement design, structures, and median barriers. To permit this work to be undertaken, the organization's size was increased about 50 percent in 1962 to a total of 51, and it was designated the Bureau of Physical Research. Its reputation continued to grow, resulting in requests for research in still broader areas of Department activities such as maintenance, building construction, and all facets of highway and bridge design and construction. Consequently, the research staff was increased in 1966 to its present size of 157 engineers, technicians, and support personnel.

In view of the broadened research responsibilities acquired over the years, the title "Bureau of Physical Research" came to be considered too restrictive to describe the organization's actual activities. Consequently, in 1969, the name was officially changed to the Engineering Research and Development Bureau.

B. Goals of the New York State Department of Transportation

State goals in transportation have often been stated in legislation, and were summarized in the 1967 Transportation Law as adequacy, safety, efficiency, and economy. They were officially elaborated in 1968 by the Department in terms of the roles in which people participate in the transportation system:

> "For the Users--individuals and corporations--of transportation facilities and services: reduce accidents, increase mobility, ensure dependability, reduce user costs, reduce user time, reduce effort and increase comfort, and enhance visual features of transportation facilities.
>
> "For the Providers--common carriers as well as federal, state and local governments: reduce construction costs, maintenance costs, and operating costs.
>
> "For the Community--the general public living and working along-side transportation facilities and affected by them: reduce pollution from transportation sources; increase accessibility; reduce disruption, dislocation, and negative effects caused by construction of transportation facilities; and encourage desirable physical or economic patterns."

C. Functions of the Engineering Research and Development Bureau

The Department's engineering research agency assists in attaining the goals just enumerated through five major functions:

1. *Identifying and defining subjects that are researchable--that is, suitable and manageable for study.*

Many problems are submitted to the research group for solution. It is vital that these ideas be carefully screened to determine which are unsuitable for research, which can be solved with technical knowledge currently available, and which require further investigation to obtain a solution. Considerable effort is involved in defining a worthwhile investigation--there are no shortcuts in the path from an idea for research to a project statement. Engineers knowledgeable in research procedures must consult with those in operating units who have firsthand data concerning the problem. The entire success of the research effort hinges on their ability to identify and define the research subject precisely.

2. *Formulating long- and short-range engineering research programs, based on the most favorable benefit/cost ratios.*

There are always many more suitable research projects than funds and personnel to carry them out. Therefore, each project must be analyzed in order to determine a best estimate of benefits in relation to costs. This process establishes a rank ordering for projects, which is essential in planning both for the present and the future.

3. *Conducting necessary experimental work in-house, or administering contracts for its progress elsewhere.*

Research may be progressed either by staff or by contract. This Bureau's policy has been to staff for engineering research projects dealing with applied problems in transportation technology. Research contracts have been reserved for basic research requiring a technical competence outside that normally encountered in civil engineering.

4. *Disseminating research findings and actively engaging in their implementation throughout the Department.*

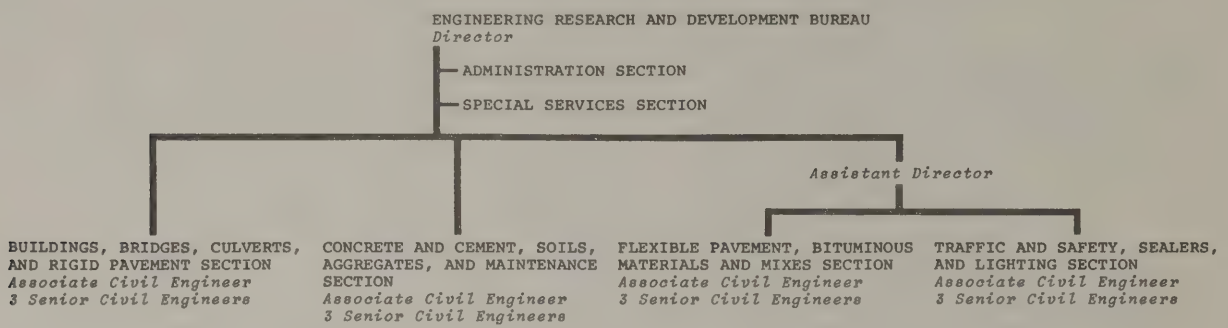
Dissemination of research findings is essential for avoidance of duplication of expenditure and effort, and so that the entire transportation industry can be made aware of the latest available technology. Within the Department of Transportation, however, mere awareness of research results would have little effect on policies and practices without a vigorous program of implementation. Experience has shown that a research report by itself is not sufficient to bring about change. Research results must be "sold" to those responsible for instituting changes. Additional explanations are usually required, questions must be answered, and the person responsible for implementation of the improved specification, standard, or method expects assistance in getting the word to those who must ultimately put idea into practice.

5. *Maintaining technical competence in all aspects of engineering that pertain to Department activities, including keeping in touch with new engineering research developments throughout the world.*

A primary responsibility of the engineering research group is keeping abreast of the latest technical developments achieved through the efforts of other researchers throughout the world. This is accomplished by formal exchange of research publications, continuing review of the technical literature, attendance at professional meetings, and membership on committees of various technical organizations. The "literature explosion" that has occurred in the last 20 years, has made this responsibility time-consuming, and the vast number and great complexity of technical developments continually becoming available permits the individual engineer to maintain competence in only a relatively narrow sector of his profession. The value of this facet of a researcher's responsibili-

ties is often underrated, resulting in research duplication and costly delays in putting the latest engineering advances into practice.

Finally, the Bureau's current functional organization is illustrated in the following chart.



II. RESEARCH ACCOMPLISHMENTS: INCREASED SAFETY

A. Guide Rails, Median Barriers, and Bridge Rails

While only about 20 percent of auto accidents on the state highway system are classified as "ran off road" or "hit fixed object," this type of accident accounted for 35 percent of fatalities in 1968 (over 300 deaths). It is readily apparent that any highway improvement appreciably decreasing such accidents or reducing their severity can make a tremendous contribution to highway safety.

Another major source of highway fatalities is cross-median collisions. In 1961, at this study's inception, only 8 percent of the accidents on divided highways in New York resulted from vehicles crossing the median. However, this 8 percent contributed 62 percent of the deaths due to accidents on divided highways. In recognition of the major improvement in highway safety possible through the development of better highway barriers, the New York State Department of Transportation nine years ago undertook a comprehensive research program on guide rails, median barriers, and bridge rails.

Wholesale installation of structurally adequate barriers would probably reduce fatalities on both divided and undivided highways, but the barrier itself may become a serious hazard. For this reason, this study was aimed at developing barriers that would redirect a vehicle so as to maximize the possibility of the occupants surviving the impact while minimizing the danger to adjacent and following traffic.

To accomplish this goal, the New York investigation has consisted of two major parts: mathematical analysis and full-scale dynamic testing. In the mathematical analysis, equations were derived to describe vehicle reaction during impact with a barrier. Vehicle characteristics, approach speed, and angle of impact, and barrier characteristics were used to predict vehicle deceleration, exit speed, exit angle, and barrier deflection. These equations were programmed for computer solution and the resulting analyses have led to new design concepts and have suggested modifications to existing barriers. In addition, a series of full-scale tests have been performed to evaluate typical barriers installed on New York State highways, barriers used by other agencies, and new barrier designs suggested by the mathematical analysis. Comparison of measured vehicle responses with mathematically computed reactions

also provided the data necessary to verify the predictions of vehicle and barrier reactions.

As a result of this investigation, the New York State Department of Transportation began installing new barriers about five years ago on new construction and safety improvement projects. Reductions in accident severity have been recorded, and international reaction to the study and resulting designs has been extremely favorable.

B. Breakaway Poles and Vehicle Decelerators

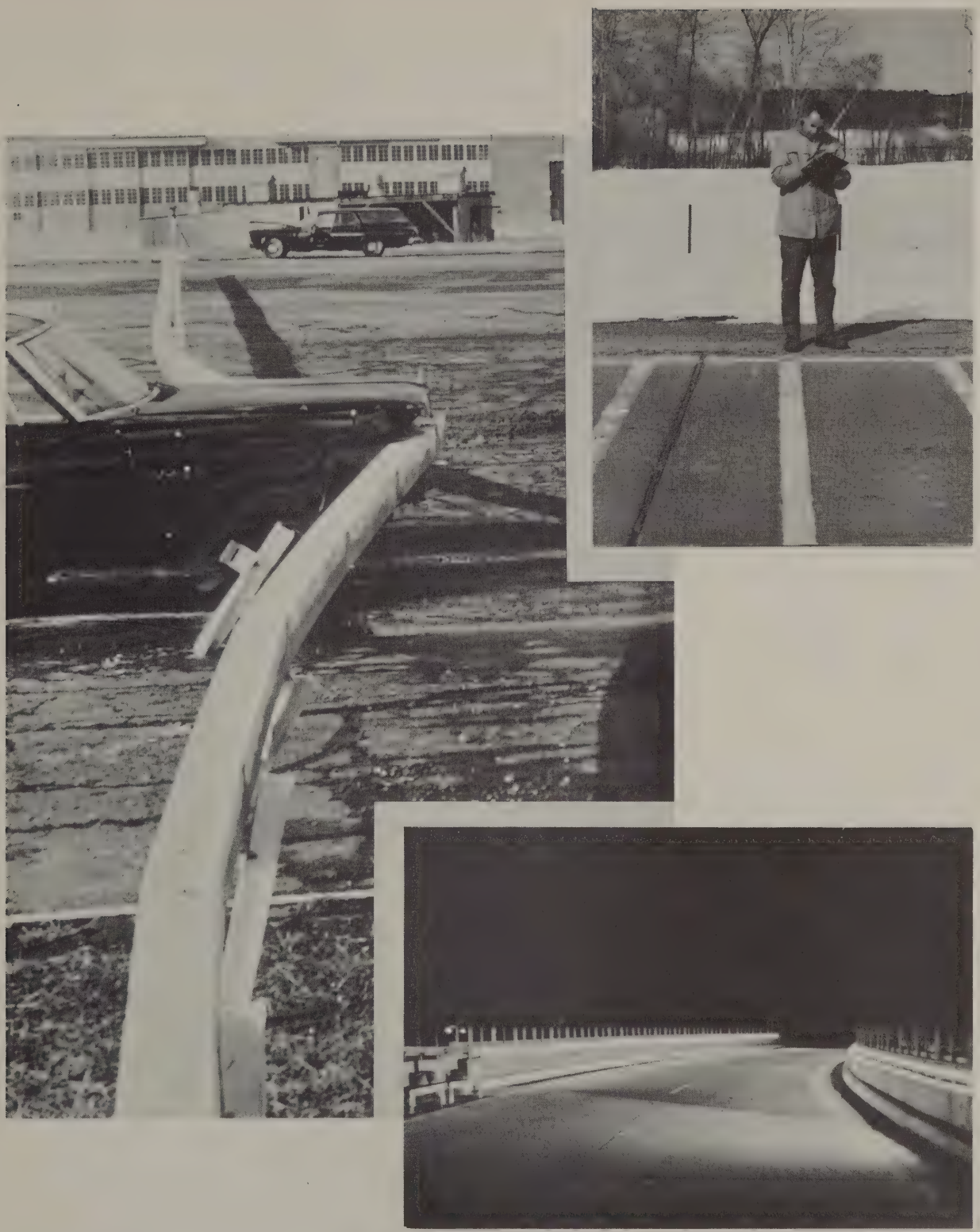
While this agency has not performed the primary research on slip-base sign supports, we have been actively engaged in evaluating these concepts, making modifications as appropriate, and performing full-scale tests as deemed necessary. For example, the Texas slip-base sign support has been modified to give way when hit anywhere within a 30° arc (original design: 15°), and full-scale tests have been performed on a multi-directional slip-base. The work on breakaway light poles has received careful review, as have studies involving vehicle decelerators. Several full-scale tests have been run on a type of vehicle decelerator that is completely free-standing and requires no anchorage units.

Slip-base sign supports are now erected as "standard" as are breakaway light pole bases. The free-standing vehicle decelerator has been included in one contract and approximately 150 more installations of this and other styles are already in the preliminary-plan stage.

Admittedly, it is difficult to access the value of these life-saving features on our highway system. However, accident information gathered specifically to evaluate the new barrier designs indicates a 42-percent reduction in fatalities, and since 46 people were killed in collisions with guide rails in 1966 this would mean that 19 lives might be saved annually. In addition, if the recently installed slip-base sign supports and breakaway luminaire standards reduced fatalities by 50 percent, 15 lives might be saved, and vehicle decelerators might prevent another 6 deaths annually. Assuming some injury in each accident, the potential saving could still be estimated at $50,000 per life, thus amounting to an annual saving of $2 million.

C. Pavement Slipperiness and Skid Resistance

In New York State, nearly one-fourth of all fatalities and serious injuries in highway accidents occur on wet roads. Obviously, by building skid resistance into road surfaces a significant improvement in highway safety can be achieved. The Bureau has studied



Safety-oriented research has included improvement and innovation in guide rail design, extensive field testing of pavement marking paints, and better night visibility through rail lighting of bridge decks.

the factors affecting the skid resistance of asphaltic concrete pavements for eight years. The initial steps were to develop a skid test trailer and a test procedure, and then to test numerous new and old bituminous surfaces. The wet pavement coefficient of friction was found to decrease as traffic used the road until a nearly stable value was reached after 5 to 10 million vehicle passes. By testing roads with this accumulated traffic, it was learned that the largest size aggregates, rather than the fines, control the final skid resistance of bituminous pavements. Mixes containing either 1) 20-percent hard coarse aggregate (non-carbonates) or 2) carbonate aggregate (limestone or dolomite) with 10-percent hard acid-insoluble impurities, remained skid-resistant for the life of the pavement surface. Based on these findings, Department specifications for Item 51 (top course) have been changed to prohibit exclusive use of coarse aggregates that resist polishing and cause pavements to become slippery. These unacceptable aggregates must now be upgraded by addition of at least 20-percent hard, non-carbonate coarse aggregate.

Research on concrete pavements is just beginning, but as an immediate measure to improve their skid-resistant life, a transverse broom finish is now required on all new construction. A number of other texturing methods will also be evaluated. Research is continuing on methods of upgrading older concrete surfaces that are structurally sound, but low in skid resistance, including grooving and texturing, acid etching, sand blasting, and applying a slurry seal containing silica sand.

During the summers of 1968 and 1969, the skid resistance of the entire 14,000-mile state highway system was inventoried. A skid test was made every mile to locate all slippery sections, and to determine the magnitude of the slippery road problem in New York.

The National Safety Council estimated that nationally in 1968 the cost of injuries, insurance administration, and property damage was $11.3 billion. Since 6 percent of the nation's highway fatalities occur in New York State (3,000 of 50,000) and since one-fourth of this state's accidents occur on wet roads, 1.5 percent of this $11.3 billion or $170 million represents our cost of wet weather accidents. If slippery pavements are a contributing factor in only 1 percent of these accidents, then $1.7 million could be saved annually by their elimination.

With regard to another critical area for skidding accidents--slippery bridge decks caused by winter icing--the effectiveness of polyurethane foam insulation sprayed on the underside was evaluated by the Bureau in trial installations. From temperature measurements recorded continuously over two winters, together with on-site observations during freezing weather, this insulation was found to be ineffective. In fact, it was concluded that this treatment would significantly increase the possibility of icing by maintaining below-freezing temperatures longer than uninsulated

decks. As a result, a potential investment of approximately $10,000 for each bridge so treated was averted. Considering the seriousness of the bridge deck icing problem and the importance placed on this study, it is reasonable to assume that if successful, the use of insulation would have been incorporated in new construction. Based on an average annual production of about 300 bridges, a recurring annual saving of $3 million has been realized.

D. Set-Back Sign Supports

Curved supports for highway signs, set back 30 feet or more from the pavement edge as a safety measure, might improve chances for survival of drivers who stray onto the shoulder. A design of this type, conceived by former Chief Engineer Robert W. Sweet, was investigated by the Bureau. The investigation's primary objectives were to evaluate stresses induced in the structure by dead and live loads, and thus to determine whether fatigue is a critical design condition. In addition, the structure's aerodynamic behavior was observed. Structural performance of this sign support was satisfactory during this period of field observation. The Bureau's report has been noted favorably by the Federal Highway Safety Administration, and has been given special distribution to the states by the U. S. Bureau of Public Roads.

The Department has expressed interest in statewide adoption of this design. In addition to the potential accident reduction, this type of sign should produce substantial economies as compared to the "over-the-highway" sign that it can replace.

E. Pavement Marking Materials

Paint is the material most commonly used for delineating highway lanes and denoting no-passing zones. To make these markings visible at night, millions of tiny glass spheres are added to the paint lines. These spheres add to the line's brightness by reflecting light from a vehicle's headlights back to the driver. Since 1963, the Bureau has been testing paints on both bituminous and concrete surfaces. Principal findings to date indicate that the Department's standard modified alkyd paint performs as well as most other paints and better than some, even though many of those tested cost several times more.

A major saving in the cost of striping with this paint was realized when the Materials Bureau reduced the titanium dioxide content in white paint from 60 to 40 percent. Tests of these paints by our Bureau confirmed that paints of the two formulations did not differ in performance. This reduced paint cost about 50 cents per gallon. Based on last years use of approximately 300,000 gallons of white paint, savings for that year alone would be $150,000.

Other studies found that addition of chlorinated rubber to the Department's paint at an increase cost of 20 cents per gallon was unwarranted. Also, a water-based emulsion paint that could be manufactured by Prison Industries was not found to be sufficiently durable to permit its use on state highways. Similarly, pretreating the pavement surface by etching with acid or by using a synthetic rubber primer served only to increase cost without increasing paint life.

A study in collaboration with the Division of Traffic Engineering and Safety during 1968 revealed that performance similar to that obtained with the Department's paint could be obtained from another formulation heated to 120 F prior to application. The advantage of this new paint was a drastic reduction in drying time to only 2 or 3 minutes--an important consideration on busy urban routes where it may be difficult to detour traffic for the 20 minutes normally needed for freshly painted stripes. This new paint's cost is comparable to the old. Although this does not translate into a direct saving, an indirect one is the increased safety for stripers and motorists in not having long sections of highway obstructed after the lines are painted.

An in-depth Bureau study of striping costs showed that of the 1.7 cents per lineal foot that it cost to stripe in 1963, only 36 percent went for the paint. Using this figure and a 6-percent interest rate, a table was developed showing how long a paint costing X dollars must last in order to be considered economically better than the state's standard paint.

In 1966, consideration was given to revising the specifications for glass beads to require a one that reflected more light. However, upon test rapid loss of these beads from paint stripes was discovered, eventually resulting in less reflectorization than existing methods. Thus, a contemplated additional cost of 2 cents per pound was saved on an annual bead purchase of 2.3 million pounds, for savings of $46,000.

Thermoplastic pavement markings, although more expensive, have been found economical in some installations. Performance on bituminous pavements has been satisfactory for up to 6 years. On concrete surfaces, however, an epoxy primer has been found necessary to obtain performance similar to that on bituminous surfaces.

It is difficult to place a price tag on having lines and markings visible the year around and especially at night. If only one life is saved annually and a life is considered to be worth $100,000 then a savings of $100,000 is realized.

In summary, it appears that about $150,000 is being saved annually by not using 60-percent titanium dioxide in our white paints, $60,000 by not using chlorinated rubber and $46,000 by using the standard glass beads. These savings annually total $256,000.

F. Bridge Rail Lighting

In 1964, the Bridge Subdivision proposed an investigation of the feasibility of lighting the pavements of a complex multi-level interchange with low-mounted flourescent lamps placed either in or below the bridge rails. The purpose was to reduce driver confusion caused by glare from numerous overhead luminaries on adjacent ramps as well as to cut the number of posts that present special safety and maintenance problems on bridges. The Bureau conducted an intensive field investigation of various lamps and ballasts for their illumination properties, glare, mounting height, spacing, visibility of various objects, effects of weather, delineation properties, and effects on drivers. Initial and operating costs of overhead and rail lights were also compared. It was determined that use of such lighting was entirely feasible, consequently, specifications have been developed for such lighting on the new South Mall River Front Arterial interchange in downtown Albany.

G. Glare Screens

Yet another aspect of the overall problem of night visibility came under Bureau examination in 1968. Information has been gathered on how satisfactory various types of screens have been in eliminating the hazard of glare from opposing traffic, particularly on divided highways with narrow medians. Installations in New York and neighboring states have been inspected. Their effectiveness has been clearly established, but work remains in determining the advantages and disadvantages of various types in differing situations.

H. Audible Roadway Delineators

Complementing the Bureau's studies of visual aspects of safety on the highway, an investigation in progress is centering on the aural side--so-called "rumble strips." Twenty agencies and installations have been visited in eight states. The consensus is that such delineators are definitely effective, but that the variety of designs available must be narrowed by research to a reasonable range of configurations and materials. After observing test installations at representative locations, the Bureau will recommend those best suited to various situations, for ultimate large-scale use throughout the state.

III. RESEARCH ACCOMPLISHMENTS: ASSURED QUALITY OF MATERIALS

A. Aggregates

1. Inventory Services

One of the new Bureau's first projects was to provide an inventory of fine and coarse aggregate sources for the Department and the mineral aggregate industry in general. In 1961, a report was published describing the locations and geologic characteristics of more than 120 commercial sources of concrete fine aggregate within New York State. Also included were generalized information on the physiography of New York, and on the use of landform, depositional environment, and agricultural soil series names as keys to engineering characteristics of the source. In 1961, a second report was published covering 79 commercial quarries that supply crushed stone coarse aggregate. A brief geologic history of the state was included. All of these reports included original geologic work.

These reports have received extremely wide circulation in New York among both consumers and suppliers of aggregate and other construction materials, as well as among educators, planners, and consulting engineers. They have been widely used as references in New York colleges and high schools. Within the Department, they were the first important step in developing more systematic, more thorough control and acceptance procedures for aggregates.

Subsequently, a large volume of new information has been developed on the basic physical and chemical properties of many aggregate producing bedrock formations, as well as their engineering properties.

2. Crushed Gravel Coarse Aggregate for Asphalt Concrete

Experimental crushed gravel pavements are performing as well as comparable crushed stone pavements. Crushed gravel shows better skid resistance than crushed stone aggregates. Although most areas of New York State have substantial supplies of crushed stone for use in asphaltic concrete, the southwest portion is an exception. Stone must be imported, since locally available gravels are seldom used in the Department's asphaltic

concrete mixes. Current average costs for transporting aggregates, depending on proximity to market and geographic location, are about 6 cents per ton mile. When aggregates must be transported 50 to 70 miles, use of local aggregate would constitute a saving of $2 to $3 per ton in hauling charges. The estimated annual savings to the Department from permitting use of gravels would exceed $20,000.

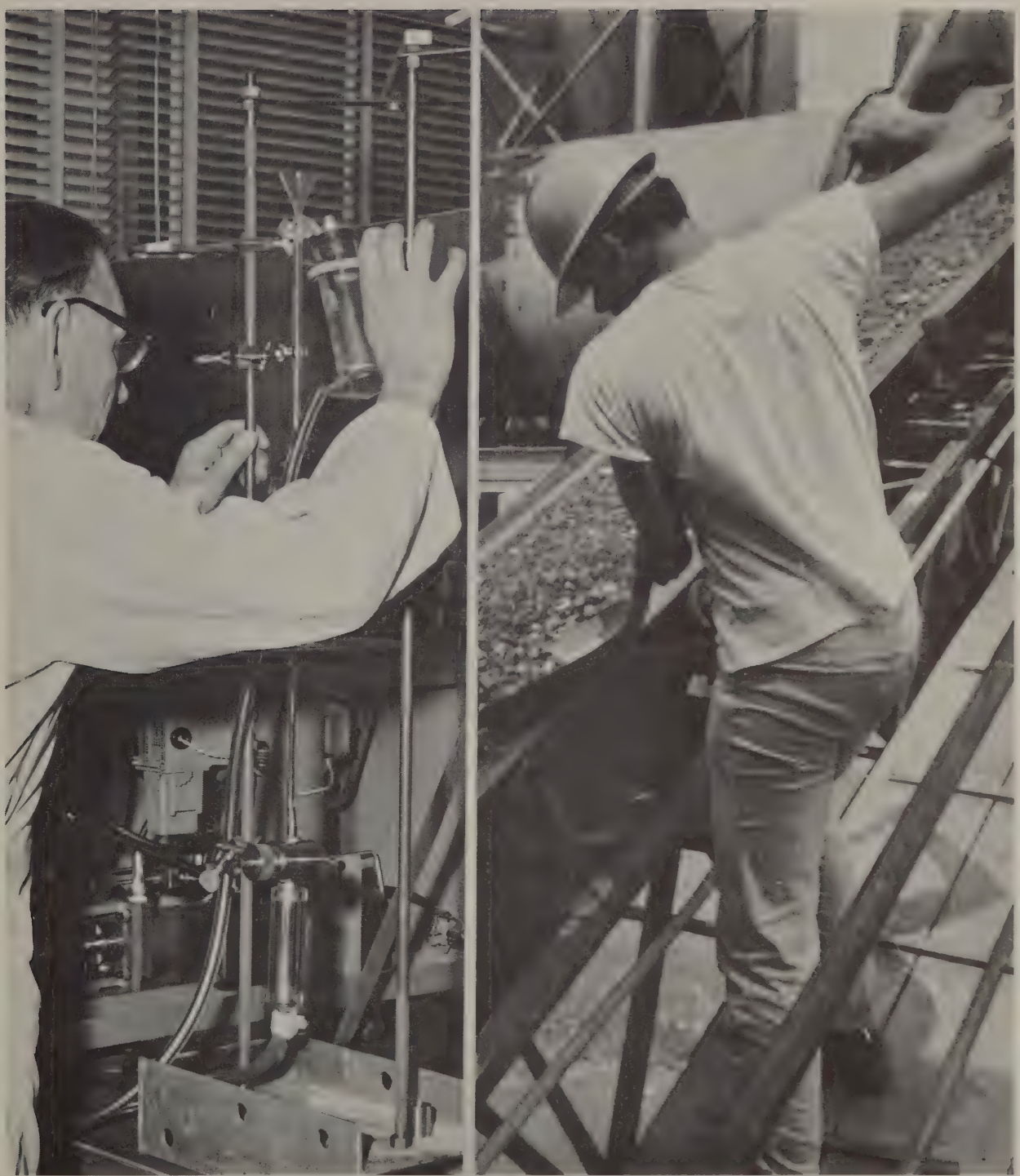
3. Testing Crushed Stone for Concrete

Not only is the Department one of the largest users of aggregate materials in the state, but its specifications are the model upon which many local codes and specifications are based. The development of procedures for making correct judgments about the quality of aggregate materials is of paramount importance in evaluating long-range plans for efficient use of such natural resources.

A major effort is being made to develop acceptance testing procedures for coarse aggregates that measure or reflect those properties actually governing performance in concrete. Existing procedures, although widely used, are highly empirical.

Extensive field surveys of air-entrained concrete in central and western New York have established the excellent service records of aggregates from formations supplying most of the crushed stone and aggregate to that area. These surveys also indicate that while the procedures used to judge aggregate soundness have generally been effective in preventing use of deleterious materials, they have probably also been responsible for rejection of good material that could otherwise have been used. Research currently underway may develop more definitive acceptance-testing procedures for concrete coarse aggregates.

In acceptance tests involving physical properties of stone aggregates used in concrete, two investigations dealing with abrasion resistance have been completed. Careful appraisal of the test procedure specified by the Department has provided information pertinent to decisions concerning the acceptability of aggregates. If unsound, these aggregates could adversely effect concrete quality. In addition, an alternate procedure recommended from this research because of its superior reliability and its simplicity has been used on a trial basis and may be adopted as the acceptance standard. The new procedure will permit savings on the order of 600 man-hours of laboratory testing annually, as well as insuring improved reliability of test results. Assigning a personal service cost of $5 per hour for laboratory manpower, the annual payroll savings alone amount to $3,000.



Research toward improved quality of materials has ranged from intensive laboratory testing to sampling during the construction process.

4. Testing Sand for Concrete

Since early in its work, the Bureau has devoted considerable effort to reviewing and updating the Department's specifications for concrete fine aggregate. The most effective and direct way to judge the acceptability of an aggregate for concrete is to examine the properties of concrete containing it. However, this is expensive, slow, and virtually unworkable for the large number of individual producers whose products are sampled and tested by the Deaprtment each year. This Bureau's research, therefore, has been directed at determining the significant concrete-making properties of fine aggregates, and at evaluating various simple test procedures that measure or reflect those properties.

One major outcome has been the demonstration that the freeze-thaw durability of concrete is virtually independent of fine aggregate quality as measured by magnesium sulfate salt soundness--a standard, widely-used acceptance test for which is claimed some relevance to frost resistance. A second major finding was that many properties of fine aggregate that affect the properties of plastic and hardened concrete are highly related to one another. The Department thus has been advised to retain the magnesium sulfate soundness test to judge the relative quality of fine aggregate, not because it has any relation to frost resistance, but because it correlates significantly with such other important concrete properties as water retention and shrinkage. A number of other procedures (including the California sand equivalent test, popular in many western states) were also evaluated and rejected as acceptance tests for concrete sand in New York.

Various recommendations were also put into effect to improve the reproducibility of the magnesium sulfate soundness test. Errors associated with testing were measured and a guide was prepared for evaluating test results in view of these errors. Other phases of this work have resulted in the following recommendations, most of which have been incorporated into specifications:

a. That the sodium sulfate soundness test be eliminated (estimated annual saving: $8,000).

b. That the rational analysis test be eliminated (estimated annual saving: $15,000).

c. That the practice of classifying sands into quality categories be discontinued, thus allowing a greater field of acceptable sources in certain parts of the state.

d. That fine aggregate from sources consistently producing a very uniform, high-quality product be accepted by cursory microscopic examination only (estimated annual saving: $6,000).

e. That the range of allowable gradation be broadened to conform to ASTM specifications and that requirements for the Nos. 8 and 28 sieve sizes be inserted in the specifications.

f. That the allowable quantity of material passing the No. 200 sieve be increased from 1 to 2 percent.

5. Chert as a Concrete Aggregate

Highly porous chert may cause concrete deterioration in a freezing environment. Certain cherts will also react chemically with cement alkalis and so cause deterioration. Because these problems have been widely publicized, chert in New York was suspect in the early 1960's, and action had begun to restrict its use. Chert is a major constituent of the Onondaga limestone formation, which accounts for about 50 percent of crushed stone aggregate production in central and western New York. Research by this Bureau was responsible for preventing such restrictions, which would have had serious economic consequence. The Onondaga cherts were shown to be potentially chemically reactive with high alkali cements, but extensive field surveys and investigation of specific failures failed to turn up any instance of concrete failure actually attributable to alkali-chert aggregate reaction. This apparent contradiction undoubtedly resulted from the fact that little high-alkali cement has been used in that area.

This research had the following results: 1) all restrictions on use of chert aggregate in concrete were removed from specifications (for example, Item 18M); 2) the Department purchased flame photometer equipment to measure cement alkalinity and cements are not regularly tested for this property, and 3) procedures were adopted to prevent the introduction of cement with alkali content exceeding 0.7 percent into the area where chert is common.

Although it is difficult to place a dollar figure on Department savings from this project, an approximation can be made. Last year over 400,000 cubic yards of concrete were used in central and western New York. Of this total, about half contained crushed stone from the Onondaga formation. If this stone were not used, stone from the Lockport formation would have been substituted, increasing the haul distance of the stone an average of 25 miles. This would amount to at least $1 per ton. Since about a ton of stone is used for each cubic

yard of concrete, the increased cost to the Department would have been approximately $200,000.

6. Portland Blast-Furnace Slag Cement

At the request of Region 8, the Bureau documented experimental use of portland blast-furnace slag cement in new pavement constructed near Chatham, New York. This product makes use of an industrial by-produce of pig iron ma-ufacture and has been used successfully in Europe since the late 1800's. This installation was the first reported use of slag cement in New York, in anticipation of an expanding local market. Documentation of this project, together with studies in other parts of the country, led to the conclusion that existing ASTM and Federal specifications provide adequate assurance of performance comparable to other general-purpose cements, and established the suitability of this material in pavement concrete.

B. Cement and Concrete

1. Determining Air Content and Other Mix Proportions

Concrete used in a freezing environment must contain an adequate volume of small, artificially entrained air bubbles to protect it from frost damage. The Bureau has built two pieces of equipment for estimating air void characteristics of hardened concrete, and has developed procedures for their operation:

a. A high pressure device to measure total air content of a sample of hardened concrete is now used in routine acceptance tests for precast concrete curb, curb and gutter, and cribbing.

b. A microscopic device (linear traverse) for estimating total air content as well as other characteristics of the concrete air void system is used both for research and in trouble-shooting problems of concrete deterioration. In the last 5 years, for instance, the Materials Bureau has conducted 42 different investigations involving study of 172 samples of concrete with this equipment. It can also be used to determine cement content and water-cement ratio at the time of placement.

Studies by the Bureau have also resulted in recommended procedures for interpreting tests for air content of plastic concrete with the Chace air indicator. An investigation of the effect of using different types and concentrations of alcohol with this device resulted in standardizing on a 99-percent isopropyl alchol solution.

2. Low-Porosity Cement Pastes

Research at Clarkson College, supported by the Department since April 1966, has resulted in the development of a new type of portland cement that can produce workable pastes (mixtures of cement and water) at water-cement ratios of 0.2 by weight, as compared to 0.45 to 0.65 for normal concrete. The new cement produces strengths three to four times greater than normal portland cement, and reduces drying shrinkage to about one-third. This research could lead to breakthroughs in concrete technology comparable to the discovery of air-entrainment. Precast concrete units made with this new cement, for example, could be used as bridge decks to increase durability and decrease dead load. Other structural numbers in bridges and buildings can be significantly decreased in size, while having the same strength as normal concrete.

3. Histories of Cements in Experimental Pavements

One of this Bureau's first studies examined all experimental concrete pavements constructed in New York since 1929, in which numerous types of cements were used. The main objective was to determine whether cement type, as distinguished by chemical and physical properties, influenced pavement durability under actual conditions of field exposure. No correlation was found, a conclusion which together with the findings of other related investigations provided a rational basis for improving the state's cement specifications. As a consequence, current cement requirements are less restrictive, and the competitive market has been broadened.

4. Laboratory Studies of Portland Cement

Laboratory studies conducted by this Bureau have resulted in several changes in the Department's specifications for portland cement:

a. The maximum allowable content of sulfur trioxide was raised for all cement types to permit manufacturers more latitude in the amount of gypsum they add. By allowing more mills to attain their optimum gypsum content for strength, this action has increased the general strength level and durability of cements supplied to the Department.

b. The autoclaving of cement clinker was discontinued as a measure of cement soundness in deference to ASTM C 151, ("Standard Method of Test for Autoclave Expansion of Portland Cement"). The latter procedure gives a more definitive measure of those characteristics of cement that affect its performance.

c. ASTM C 109 ("Standard Method of Test of Hydraulic Cement Mortars, using 2-in. Cube Specimens,") was substituted for ASTM C 190 ("Standard Method of Test for Tensile Strength of Hydraulic Cement Mortars") on the basis of demonstrated greater reproducibility.

5. Concrete Specifications and Sampling Plans

Through Bureau efforts during the summer of 1967, the Department for the first time obtained an objective measure of the properties of portland cement concrete placed in pavements and structures built under contract to the Department. These items represented an expenditure in excess of $100 million during that year.

It was found that variations in slimp, air content, and 28-day compressive strength were considerably greater than tolerances allowed by Department specifications. However, these variations were no greater or less than variations observed by other investigators gathering similar data in other parts of the country. As a result, Department specifications for concrete slump and air content were altered so as more realistically to reflect the variations that appear to be inherent in the concrete manufacturing process. All data derived from this research have been placed in a national data bank on construction materials variability maintinaed by the U. S. Bureau of Public Roads.

Work is continuing to develop and evaluate statistically-based acceptance sampling plans for concrete that reflect these variations. By increasing control on the quality of concrete used on Department projects, significant savings may be realized. Field surveys indicate that a small percentage of concrete used in New York deterioration the Department could save $1 million annually.

C. Bituminous Materials

1. Asphalt Hardening

The quality of asphalt cement used in state asphalt concrete mixes has been a matter of considerable concern, especially the need for consistent performance of asphalt cements from their initial introduction into the asphalt plant pugmill to their laydown, compaction, and in-service life in the pavement. Asphalt hardening (i.e., loss of consistency) is not a phenomenon new to asphalt technology. However, its presence in New York State pavements was not considered a matter of concern, until a neighboring state reported a rash of occurrences in

its pavement. As a result, former Commissioner McMorran requested a comprehensive study to determine if early hardening was occurring here, since asphalt cement sources are sometimes common to several adjoining states. Results showed some isolated cases of hardening, but it was determined not to be a major problem. However, those cases did emphasize to Department inspection personnel the importance of proper mixing and rolling temperatures--that is, not overheating the asphalt cement prior to introducing it into the pugmill, but being sure the mix is compacted before it gets too cold, so as to assure optimum void content. The study showed that the Department's asphalt cement quality control procedures were adequate to assure a viable material. It also provided a comprehensive data bank on asphalt cement performance for future use in efficiently predicting maintenance resurfacing needs. In addition to the other benefits derived from this study for construction inspection, were those developed for future mix design studies.

2. Admixtures and Additives

As with any good product, efforts are constantly being made to improve the performance characteristics of asphalt concrete by selective addition of such materials as asbestos, talc, hydrated lime, and rubber. Over the past 10 years, various Region offices and the Maintenance Division have constructed test installations of such asphalt concrete mixes, and invited the Bureau to evaluate their performance. Results showed that with the Department's rural-highway surface course mix, these materials did not improve pavement performance, and therefore in no way justified their cost (i.e., an increase in price per ton of approximately 10 percent). Based on the Department's yearly tonnage of surface course mix, this negative saving amounts to almost $50,000 annually if as little as 10-percent of the top course mixes were to contain admixtures. These results do not mean that additives and admixtures can never prove beneficial to asphalt concrete performance. For example, under special conditions and with special mixes (e.g., steep grades, heavily traveled intersections, and bridge decks) they might extend pavement service life and therefore appropriate study is continuing.

3. Asphalt Cement Viscosity

The quality of asphalt cement has a great effect upon the durability of the asphaltic concrete highway in which it is used. Currently, the penetration test is used by the Department in specifying paving asphalts. The viscosity grading system is a marked improvement over penetration grading, since it con-

trols flow properties over a wide temperature range, and reflects the material's true engineering properties. For this reason, the Asphalt Institute, AASHO, and many states have been formulating proposed viscosity specifications. Pennsylvania has already switched to viscosity grading.

A recently completed study has inventoried asphalt cements supplied to New York State as to both penetration and viscosity. The data accumulated give a very comprehensive picture of the state's position in relationship to proposed grades. While we are receiving excellent asphalts now, it is extremely important that we continue to receive a comparable produce under any grading system.

If other nearby states switched to viscosity grading and New York held back due to lack of an acceptable specification position, asphalt suppliers would have to keep separate tanks of asphalt to supply this state. This situation would result in significantly higher prices for asphalt cement.

4. Uniformity of Mix Gradation

A major effort has been expended to determine the gradation uniformity properties of the Department's asphalt concrete top course and binder course mixes, and to a lesser extent those of its base course mix. As with other Bureau research projects, this particular study has been in the forefront of national efforts towards quality control of highway materials.

5. Computer Simulation of Plant Production

In addition to upgrading gradation tolerances, the data gathered during these uniformity studies have been used in improving the Materials Bureau's asphaltic concrete quality control procedure. Without a realistic description of the uniformity properties of such mixes, truly meaningful quality control procedures could not have been developed. A study has just been completed in which the gradation output of a typical asphalt plant was simulated in the computer, so that a completely optimized quality control procedure could be developed. The simulation technique permits Department researchers to perform an unlimited number of uniformity and quality control studies, in the computer, that could hardly be duplicated in the field even if unlimited personnel and funds were available. The techniques developed will also be applicable to the quality control of such other materials as portland cement concrete, aggregates, reinforcing bars, etc. Such spin-offs of information and/or techniques are common to most research studies, and are intangible benefits not readily accountable on a balance sheet.

6. Optimizing Mixing Time

In asphalt concrete mix production, it is most important that not only should aggregate gradation be uniform, but that asphalt cement coatings on those aggregates should be complete and uniform. This can be achieved only through maintaining an adequate mixing time for these materials in the asphalt plant pugmill. However, prolonging such a mixing period may result in damage to the mixture due to excessive hardening of the asphalt cement, and also in increased production costs due to decreased production output.

At the suggestion of the New York State Bituminous Concrete Producers Association, a mixing time study was conducted over a 2-year period to determine optimum mixing time for asphaltic concrete mixes produced for state contracts. The results showed that mixing-time specifications then current could be reduced appreciably for most newer asphalt plants in the state, without reducing the quality of their production. As a consequence, the Department's asphaltic concrete mixing time specifications were revised to allow production at reduced mixing times, if the particular plant's mix quality is not diminished.

Currently, more than 40 percent of the state's plants produce at an increased rate, giving them as much as 30-percent increase in plant capacity. Owners of older plants incapable of taking advantage of this reduced-mixing benefit now have potential economic gains encouraging them to modernize their facilities. A fully modernized plant is of course a direct benefit to the state since the quality of its production is markedly improved, as is the working relationship between inspector and producer. This results in fewer mix rejections and, consequently, an even-flowing paving contract. Reduction or elimination of paving work stoppages tends to relieve the contractor's uncertainty when estimating his next contract, enabling him to bid a lower price for similar paving work.

Substantial future economic benefits will derive from this reduced mixing time research when the use of hot-mix storage silos and full-width, thick-lift asphalt concrete paving become commonplace. Then, probably in the next decade, asphalt plant production will have to be multiplied many times in order to supply greater demand. Minimal mixing time and pugmills of increased mixing capacity will meet those demands, resulting in reduced overall construction costs. This reduction in mixing time is believed to have held bid price down below normally expected price increases of 5 percent annually. The savings are estimated to be 10 cents per ton on 2 1/2 million tons used annually, which would amount to about $250,000 each year.

D. Joint Sealers

A considerable portion of all pavement deterioration results directly or indirectly from inadequately sealed joints. Thus, study of joint seal materials for transverse joints in portland cement concrete pavement was initiated to determine which of the many available provided the most effective and economical seal. Initially, only liquid materials were available. Field tests indicated that liquid sealer life could be increased by restricting its depth, which resulted in reduced stresses on the sealer. As a result, the state began sealing transverse joints 1/2-in. deep instead of the previous 2 in. Although this reduction in depth required only one-quarter as much sealer as before, it was also found that a more expensive polysulfide-tar sealer gave better performance than the material being used and therefore it too was specified.

During 1960, the first preformed neoprene sealer was installed. Subsequent surveys found that when the correct size of preformed neoprene was properly installed, a service life greater than that of any liquid sealer could be obtained. Consequently, from late 1963, only preformed neoprene seals have been specified for all new construction.

Field surveys of this "new" material continued, however, and some field failures were detected. Attempts were made to compare field performance with laboratory acceptance test results and a "recovery" test. When little or no correlation could be found, a new force-deflection test and a revised recovery test were developed. Review of the failed sealers indicated that some failures could be attributed to their inability to meet certain requirements needed for satisfactory performance. To solve this, the new force-deflection test and the revised recovery test were added to the specifications. In addition, the uncompressed sealer width was increased from 13/16 to 1-1/4 in. To date, field surveys indicate all of these seals performing satisfactorily.

IV. RESEARCH ACCOMPLISHMENTS: IMPROVED DESIGN AND CONSTRUCTION

A. Corrugated Metal Culverts

Since galvanized steel culverts began to be used for highway drainage in the early 1930's, New York has installed many millions of feet--880,750 feet at a cost of nearly $6 million in 1968 alone. However, no formal effort had ever been made to determine steel culvert performance. Furthermore, over the years many design changes toward lighter gage metal were proposed and in some cases adopted. In the early 1960's several new corrugations, metal types, and design methods that resulted in substantial thickness reductions prompted the Bureau to undertake a statewide evaluation of metal drainage structures. A total of almost 800 galvanized steel pipes were inspected, varying in age from 2 to 35 years. Their metal losses were compared with such environmental factors as soil and water pH, resistivity, stream flow rate, type of topography, and age, without success. However, recent study has shown a definite correlation with the dissolved carbonate content of the stream water. Thus, it has been concluded that in approximately one-fourth of the state, lying generally in an east-west belt stretching from Albany to Buffalo, uncoated lighter-gage galvanized steel pipe could be used. Unfortunately, to do so in the rest of the state would have resulted in the loss of many structures well before the end of their design life. In fact, the data disclosed that in many areas galvanized steel would have to be considerably thicker, at a significant increase in cost. On the other hand, aluminum culverts have shown excellent performance over a 6-year period in areas detrimental to galvanized steel, and a stainless steel also appears satisfactory on the basis of laboratory tests. Thus, a competitive environment has been developed and the possibility of some drainage cost reduction appears reasonable.

More specifically, the data for 1968 show that the average pipe purchased was a 16-gage, 21-inch diameter, asphalt-coated, paved invert, galvanized metal pipe. Since the study showed that some type of uncoated metal pipe could be used statewide, and coating and paving costs of about 5 cents per inch of diameter per foot of length are applicable to 30 percent of the footage placed, a recurring annual saving of over $276,000 would result. Furthermore, assuming the lighter gages can be used in some type of metal on 50 percent of the structures, there is an additional possible recurring annual saving of about 7 cents per inch of diameter per foot of length, or another $645,000. Thus, the anticipated re-

curring annual savings from the implementation of the results of this study should exceed $921,000. Maintenance savings can only be estimated as substantial, in the absence of any data.

B. Flexible Pavement Design and Construction

Asphalt concrete pavement performance depends heavily upon the quality and uniformity of the components making up the mix (i.e., aggregate and asphalt cement). However, it is also most dependent on how well the mixture is compacted during laydown. If not compacted adequately, it will either distort under traffic (i.e., rut or shove), or the air void content will be so high that the asphalt cement will harden too rapidly. In addition, excessive air voids will allow rain water to seep more readily into the pavement, where it will destroy the bond between asphalt and aggregate. Therefore, because of the importance of proper mix compaction an extensive asphalt concrete density study was conducted upon the Department's top, binder and base course mixes. The study established basic, but highly important factors concerning the typical contractor's compactive efforts on Department mixes. It was determined that just-compacted pavement density varied significantly across the lane, being greatest in the center and least near the pavement edge. Any evaluation of pavement density based solely on record cores taken from the center of the lane would thus have given erroneous results. That is, overall pavement densities would have been assumed to be greater than they actually were--an assumption on the unsafe side. This study prevented that major error from occurring. Also, since density variation across the lane resulted primarily from the number of roller passes, this revealed to pavement inspectors the lack of balance in the typical contractor's rolling pattern. This unbalance was common throughout the state, and its detection did much toward statewide improvement of pavement densification methods.

Another factor revealed by this density study is that the laydown and compaction of a pavement course will increase the density of the course immediately beneath it. This fact will have an important influence on any future contract acceptance schemes that might consider each course's density as a norm upon which to base payment.

Pavement densification due to traffic has also been studied to establish the typical pavement's history of decreasing voids. Results to date have established that the Department's asphalt concrete pavements do densify under traffic, but not excessively. Consequently, it is not anticipated that continued increase in vehicle registration will cause any dramatic increase in the need for maintenance funds due to pavement distortion.

A new thickness design procedure is currently being developed using data collected from over 250 pavements throughout the state.

In design and construction, research is improving pavement riding quality through early monitoring and reduction of built-in roughness, providing longer-lasting sealers for pavement joints, and watching performance of new steels for bridge reinforcement.

This work has already verified the current design procedure to a large extent, but will make savings possible by permitting recommendation of more efficient designs in specific instances.

Studies into the methods and equipment used to construct bituminous pavements are also being undertaken. These will be aimed at both current practices and innovations. By studying current practices, it is hoped that the various operations can be made more efficient by eliminating, improving, or replacing specific steps in the construction procedure. Where innovations are concerned, the Bureau will initially act as a clearinghouse for pulling together results of studies conducted throughout the state. It will then conduct, and aid region personnel in conducting studies on new concepts and procedures. By centralizing the analyses, the dissemination of results and recommendations will be faster and more complete.

C. Bridge Design and Construction

1. High-Strength Reinforcing Steel

In 1960, the Department began participating in a national cooperative study by designing two concrete bridges reinforced with high yield-strength steel. Prior to construction in Rochester, the Portland Cement Association conducted laboratory load tests on scaled-down specimens of the principal supporting girders. At the request of the Bridge Subdivision, the Bureau rigorously tested the completed bridges to determine actual deflections and stresses created by the bridge weight and traffic load. The results have largely substantiated the design criteria, but also show that certain assumptions were conservative. Application of these findings to future bridges will permit more economical designs.

2. Shear Connectors

In response to interest expressed by the Bridge Subdivision, the Bureau arranged co-sponsorship of a study at Lehigh University, concerning the behavior of composite beams using stud shear connectors. Composite construction refers to the steel girder-concrete deck combination, used in most New York State bridges. Through carefully conducted laboratory load tests, the researchers found that the actual distribution of shear stresses differed significantly from the assumed pattern. This information has been implemented by the Bridge Subdivision in the form of more efficient shear connector designs. A series of publications from this study has added significantly to knowledge in this field.

3. Curved Steel Girders

A current investigation with a great potential payoff concerns field testing of horizontally curved steel girder bridges. Such bridges and elevated ramps for interchanges constitute about 20 percent of all those being designed by the Department. Therefore, any reduction in unit cost realized through improved design procedures will substantially reduce the total cost of the curved girder bridge construction program. That significant savings are in fact possible is reflected in the observation that the design of these structures is based on complex concepts of stress analysis, which attempt to predict the combined effects of such uncertain factors as varying curvature, load distribution, temperature variations, and torsional effects. Because of these uncertainties, each engineered structure necessarily embodies a high conservatism on the side of safety. It is here that the results of our studies will be applied. By monitoring the behavior of two experimental curved bridges, we expect to provide answers to the more critical questions of design. As a measure of the potential return-on-investment, the Bridge Subdivision has estimated that the results of this investigation could permit a reduction in the margin of safety currently used in design sufficient to produce annual savings on the order of $400,000 to $800,000. Therefore, the total cost of this research will be recovered during the first year that new structures incorporating the results are constructed.

4. Stay-In-Place Forms

At the request of the Bridge Subdivision, metal forms used to construct bridge decks have been evaluated to determine if serious decomposition of the forms would in time create a hazard. This question was prompted by a report that a section of corroded metal form had fallen from a bridge onto a heavily traveled highway. In 1963, 31 of the 65 structures of this type then existing were inspected by Bureau personnel. We concluded that the single incident of distress was caused by an improper construction detail, and that there was no justification for discontinuing the use of stay-in-place forms, which are often less expensive than removable deck forms.

D. Rigid Pavement Design and Construction

1. Effectiveness of Concrete Paving Mixers

This study was undertaken in 1958 to determine if the then-specified mixing time could be reduced and the specified overload increased in 34E dual-drum paving mixers. It was learned that these goals could be attained without affecting quality of the

pavement concrete. As a result, Department specifications were changed to reduce mixing time from 120 to 75 seconds, and to increase overload from 0 to 20 percent depending on pavement grades, but to permit no overload on grades steeper than 6 percent. While it is difficult to assign savings to the resulting production increase, it is interesting to note that the average bid price dropped 33¢ per cubic yard of pavement concrete between 1960 and 1961 (from $13.44 to $13.11). During these years about 700,000 cubic yards of concrete were placed, which would account for savings of $231,000--or more, considering rising construction costs.

2. Mixing and Transporting Concrete from Central Mixers

On the basis of a review of the literature concerning concrete production by large-capacity central mixers, the Bureau recommended that mix times less than 90 seconds be allowed upon the producer's request, provided he can demonstrate through appropriate tests that he can produce well-mixed concrete at the reduced mixing time. This recommendation has been reflected in recent changes in the Department's specifications allowing mixing times as low as 60 seconds. This action will result in more efficient use of equipment and manpower. For those jobs that can take advantage of a shorter mix time, it will be possible to produce and place a theoretical maximum of 50 percent more concrete than before, during an equal production period. Of approximately 30 central-mix plants operating in New York, about half have requested and received authorization to reduce mixing time from 90 seconds.

It was also recommended that haul time for concrete transported in agitated units be increased from 50 to 90 minutes so as to increase the range of operation of central mix plants. This modification is under consideration by the Materials Bureau.

3. Transverse Joint Construction

During the last decade, many methods have been used in the state to construct transverse joints in concrete pavements. Basically, these can be classified in three groups: hand-formed, insert-formed, or sawed. Field surveys have shown that each has its advantages and its disadvantages. Consequently, a technical manual was prepared for the field construction engineer to alert him to problems he might encounter with each method.

Also, field surveys indicated that joint spalling during construction was a problem, which has become more acute when the state started using compression seals. These require a joint of consistent width in order to perform properly. The Bureau

developed a technical manual on epoxy repairs, patterned after a similar repair manual of the U. S. Army Corps of Engineers but containing New York State problems. This publication has been specified as the means of repairing joints on newly constructed pavement since 1963.

To reduce failures of preformed neoprene joint sealers, it was found that either pavement slab length would have to be reduced or the joints constructed wider. Economically, it was desirable to construct wider joints, but there was concern over what effect these might have on pavement roughness. A study proved that within the range considered, there was no objectionable increase. As a result, transverse contraction joints are now being constructed 5/8-in. wide in two stages. The contractor can either form or saw initially, but then he must size the joint to 5/8 in. by sawing. This results in a consistent joint width for the compression seal. The contractor is also required to level joint edges. This eliminates an area which frequently spalled when subjected to traffic.

4. Transverse Joint Load Transfer

New York State has always used a concrete pavement design requiring transverse joints with load transfer at some nominal spacing, presently 60 feet 10 inches. Over the years many different load transfer devices have been used, and each has had its drawbacks. Doweled joints exhibited severe mid-slab cracking as a result of thermal contraction being restrained by dowel corrosion. The others all had inadequate load-carrying capacity, resulting in progressive joint faulting under heavy truck traffic; some also produced mid-slab cracks. Therefore, analysis of the relative performance of these many designs was one of the Bureau's earliest projects. Based on data for 746 lane miles where tye type of device used could be determined, it was found that the present design was the best. However, since it had some tendency to wear excessively, it was strengthened about 25 percent.

The savings from this study lie in reduced maintenance costs for rehabilitating faulted pavements. Only two procedures are used for such work. The pavement can be overlaid with a minimum of 2 inches of asphalt, or the lower side of the joint can be raised by lime-cement jacking. The former will cost about $16,000 per lane mile for the asphalt overlay, plus extra costs such as raising the shoulders and resetting guide rail. Lime-cement jacking cost $625 per lane mile in 1962, or probably about $900 per lane mile today.

It is a reasonable assumption that without the improved load transfer devices, 25 percent of the 135 lane miles of concrete pavement placed in 1968 would need corrective maintenance in

the driving lane within 5 to 10 years. Total costs for repairs to the driving lane alone by lime-cement jacking would be approximately $30,600. However, if an asphaltic concrete overlay were used for the repair, both lanes necessarily would be involved and the cost could reach $1,100,000. Since an overlay is generally used for such repairs, the potential savings in maintenance costs for each year's construction of new concrete pavements is $1,100,000.

5. Rigid Pavement Design Experiments

Construction of the eew York State's "satellite study" for follow-up to the AASHO Road Test was completed in 1968. This four-lane divided highway extends 7-1/2 miles along Route 23 between Catskill and Cairo. Thirty two-lane test sections, each 600 feet long, will permit the determination of 1) the optimum combination and design of pavement components for this environment, 2) an economical alternate for processed gravel base course, and 3) the influence of subgrade conditions on pavement performance. Potential savings from this project are very high. Based on 1968 statewide quantities and bid prices:

a. A 1-inch reduction in pavement thickness would save $1 million annually.

b. Changing to 20-foot unreinforced slabs would save $700,000 annually.

c. Eliminating load transfer devices, in conjunction with 20-foot unreinforced slabs, would save an additional $1,450,000 annually.

d. Reducing the cost of subbase material by only 10 cents per cubic yard, due to relaxed gradation and plasticity requirements, could save $250,000 annually.

6. Construction Control of Rigid Pavement Roughness

Since pavement service life is correlated with as-built roughness of concrete pavements, factors that lead to roughness need to be defined and controlled. First, however, a reliable means of measuring roughness, as early as possible after construction, has been needed. In a current study, this Bureau set the following goals: a) to evaluate means of measuring pavement roughness within 24 hours of placement; b) to determine the factors contributing to roughness, and c) to develop criteria for the construction of smoother pavements.

Results to date have been most significant. The specified practice of making multiple passes over the pavement surface

with the last finishing machine was found to increase roughness substantially and was discontinued. Slip-form paving produces pavements as smooth as conventional paving, while increasing the rate of production more than 100 percent. The use of two finishing machines (as was required in some Regions) is not necessary; one three-screed machine is adequate. Pavement placed full-width is smoother than that placed lane-at-a-time. Anticipated benefits from implementing these results are: a) an improved riding surface; b) increased pavement life, since the level of roughness determines the necessity for overlays; and c) increased paving rates, resulting in a lower cost per cubic yard. Financial benefits will obviously occur but it is not yet possible to quantify them.

7. Curing Concrete Pavements

Polyethylene sheeting and polyethylene coated burlap blankers were permitted for curing concrete pavement as a result of a research study performed about 10 years ago. This plastic is unaffected by weather, is lightweight, does not absorb water, and can be reused several times in the 3-mil thickness allowed by the specifications. Contractors apparently felt that the plastic was more economical than paper blankets, because many have adopted it for general use over the last 8 years.

White-pigmented sprayed-on curing compounds were also field-tested about 10 years ago and this informal study showed no disadvantages in their use. The compressive strength of cores removed from pavements thus cured were comparable with pavements curved with paper blankers. The compounds have the additional advantage that they can be placed a short time after the pavement is finished, thus retaining nearly all of the mix water and assuring an excellent long-term cure. Contractor interest in using this material lay dormant, however, until a couple of years ago when the Department approved their use. The labor savings involved with sprayed-on compounds was well enough documented that when allowed by order-on-contract, a rebate was made by the contractor.

E. Computer Solutions for Slope Stability Analysis

Design of cut and embankment slopes is a major service of the Soil Mechanics Bureau. Previously, this involved a time-consuming, trial-and-error process of successive analyses to find the critical failure surface for particular slope configurations. However, a program developed in 1962 in a Bureau of Physical Research project at a cost of about $25,000 has been in continuous use (with some modifications) since that time. The Soil Mechanics Bureau estimates that the dollar value of engineering manpower, which could be diverted to other activities because of this computer program,

approached $50,000 during 1968 alone. However, during this same period and for a total cost of under $2,400, the computer handled twice the number of solutions that would formerly have been done manually. In addition, the computer accurately defines the most critical failure surface, which is virtually impossible by manual analysis.

V. RESEARCH ACCOMPLISHMENTS: ASSISTANCE TO OPERATIONS AND MAINTENANCE

A. Rigid Pavements

1. Jacking and Subsealing

In the early 1960's, maintenance personnel of the New York State Thruway developed a method for rehabilitating old concrete pavement by filling voids beneath the pavement, raising sunken slabs, and otherwise restoring the pavement to original design profile and cross-section, using a mixture of portland cement and finely ground limestone. Concurrently, the State was using hot asphalt cement for the same purpose. In 1962, the former cost about $625 per lane mile and the latter ranged from $800 to $2,800. The Bureau was requested to compare them.

Lime-cement jacking was generally found to be as effective as its proponents claimed, but asphalt cement subsealing did not fill the voids completely and was extruded from joints and cracks by passing vehicles. We recommended that asphalt subsealing be discontinued, and lime-cement jacking used. Based on data from weighted bid averages since then (1965), only $100,000 has been spent on subsealing. If this practice had continued at its former rate, the average annual cost would have been $300,000 (based on bid prices for the 7 years preceding the study). In the absence of any information to the contrary, it is assumed that when subsealing was discontinued, jacking was not substituted. Therefore, annual savings from this study are estimated at approximately $300,000.

2. Epoxy Bonding Compounds

An exhaustive study of epoxy-based bonding compounds for rehabilitation of concrete surfaces was conducted for the Bureau by Rensselaer Polytechnic Institute during 1962 and 1963. The results of this very successful work produced an epoxy resin formulation suitable for a wide variety of construction applications. Today, virtually all operations requiring bonding new concrete to old, repair of holes and spalls, and protection of bridge pier caps and abutment backwalls are accomplished with epoxies patterned after the developed formulation. Performance

of these epoxies has been significantly superior to the materials used previously, and their greater service life is substantially reducing costs associated with repetitive maintenance. Also noteworthy is that the research has permitted a generic epoxy specification instead of brand names, thereby broadening the competitive market.

3. Protective Coatings for Concrete Bridge Decks

A statewide survey of several hundred representative bridges, conducted to assess the condition of structures throughout the state system, furnished valuable data for scheduling maintenance priorities, and identified principal forms of distress and their causes. For example, surface scaling was attributed to inadequate drainage and to variations in entrained air content, results which are expected to influence future designs and construction procedures with attendant reductions in maintenance costs. Savings also are anticipated through discontinuing use of expensive protective wearing surfaces that performed poorly.

4. Non-Destructive Testing of Bridge Decks

An examination of bridge decks has developed a correlation between destructive (cores) and non-destructive (wave pulse ultrasonics) methods. Although the wave pulse method has been found to be time-consuming, the use of the method will enable bridge engineers to better allocate funds for repairs, through more precise estimates of the deterioration.

B. Flexible Pavements

1. Resurfacing Rigid Pavements

A common remedy when a portland cement concrete pavement becomes rough-riding, due to scaling or joint faulting, is to resurface it with asphaltic concrete. This might also be done if the concrete pavement becomes slippery due to the polishing action of traffic. However, whether the reason is roughness or slipperiness, the resulting asphaltic concrete overaly usually experiences reflection cracks soon after laydown. At present, approximately one-third of the state highway system consists of overlaid rigid pavements. Almost 80 percent of the joints in these pavements are estimated to have reflected through the overlay. Based on materials cost alone, more than $250,000 would probably be required for an initial sealing of these cracks. Periodic resealing and labor costs would increase

Research for greater maintenance economies has included identifying more durable protective coatings for bridge deck concrete, and conducting deflection studies to determine appropriate thicknesses for flexible overlays.

that estimate substantially. Therefore, the economic magnitude of reflection cracking warranted a formal research project on remedial alternatives.

At the direction of a former Chief Engineer, H. Ten Hagen, a field study was undertaken to determine to what degree the insertion of wire mesh reinforcement in asphalt concrete overlays would eliminate and/or reduce reflection cracking. Use of wire mesh reinforcement was shown not to significantly retard reflection cracking, and in certain cases even compounded the problem. The paving difficulties introduced by the mesh in some instances were severe. Therefore, early elimination of this concept as a supposed solution to reducing reflection cracking benefited the Department not only economically (costs would have been doubled for overlays) but also from a construction inspection viewpoint.

This subject's importance to the Department has resulted in continued study. Efforts are now being made to establish the fundamentals involved in reflection cracking so that various solutions can be proposed and investigated on a rational basis. Other possible solutions being studied include sand bond breakers, broken concrete pavements, and sawed joints in the overlay.

2. Surface Treatments

The surface treatment is a well established highway maintenance tool. Use of proper materials and adherence to good design and construction procedures are essential in achieving desired results, such as a skid-resistant texture, improved night visibility, and a surface impervious to water.

Cut-back asphalts and asphalt emulsions are the primary bonding materials used in surface treatments. In 1960, the Bureau observed and recorded the performance of 17 highways where cationic emulsions were used. Before that time, only anionic emulsions had been used and these were sensitive to certain types of aggregate. The results showed that cationic emulsions performed well with all types of aggregate. In 1966, a rash of surface treatment failures occurred. These led to discontinuing this maintenance measure on state highways. Many roads that would have been "oiled and stoned" deteriorated due to lack of attention. This year, the ban on surface treating was lifted. The Bureau is now performing a study to establish design and construction guidelines in order to prevent a recurrence of the failures of 1966. Putting the surface treatment back into the highway maintenance scheme will save the state untold dollars in avoiding the necessity of reconstructing highways that would have deteriorated without some attention but were not traveled enough to warrant resurfacing.

3. Overlays

Overlaying bituminous pavements has been studied to determine the improvement imparted by such maintenance, from the standpoints of both extended life and structural adequacy. At present, the analysis is not complete, but does show that care should be used in selecting overlay thickness, to fit the existing situation. The end result of this study will be criteria for Region and resident engineers in determining what thickness overlay is necessary for a given pavement. The method will consist of measuring deflections with Benkelman beams, using a specific axle load. Since the beams are inexpensive and relatively simple to use, they will provide a rapid, easy determination of a pavement's need.

4. Pavement Serviceability Measurement

The Bureau has developed a Present Serviceability Equation representing flexible pavement condition at any given time. This permits relative comparisons that provide bases for determining what pavements need maintenance. This study has also resulted in a compilation of data on quantitative performance of the state's flexible pavement, and has begun to point the way to more efficiently designed pavements. This has come about through intensive analysis of factors contributing to deterioration, and their relative importance when designs are considered. Preliminary figures show that $50,000 a year can be saved by a more efficient design procedure.

5. Variations in Pavement Deflection

The Bureau has determined the range of flexible pavement deflection throughout the state, and the effect of spring thaws on deflection change. The contribution of each paving course and overlays to deflection reduction was also found. Most of this deflection work was aimed at providing resident engineers with methods for determining where to overlay and in what thickness. Data and recommendations have been supplied to Region personnel, at their request, concerning deflections and their reduction by overlays. In several instances, specific pavements have been specially investigated to determine the improvement in structural characteristics brought about by maintenance.

C. Bridges

At the request of the Regional Director, deteriorated structural concrete on bridges in the area of Rochester, New York was investigated. Concrete from seven bridges was examined in detail both

at the bridge sites and in the laboratory using various analytical techniques. Concrete from another 56 bridges in Monroe County was inspected only in the field. It was concluded that the observed damage resulted primarily from freezing of highly saturated, non-air-entrained concrete, and not from chemical reaction between aggregate from certain local quarries and cement alkalis, as was suspected. Recommendations were made for repair of the damaged bridges.

In connection with recent studies of rigid pavement blowups, Bureau engineers helped direct the Department's attention to certain types of bridge damage resulting from lateral pressure applied through bridge approach pavement slabs. This situation arises when rigid pavement joints become filled with incompressibles, and cannot close when the pavement expands in warm weather. A Bureau report included photographs that will help Maintenance engineers recognize such conditions as they are developing. The report also recommended a particular pressure relief joint design that can be economically installed to prevent further damage.

D. Protective Coatings for Guide Rails

At the request of the Division of Operations and Maintenance, the Bureau initiated work to determine the most effective, economical means of protecting beam-type guide rail on the state highway system. After a literature search, and consultation with other state agencies and of the New York State Thruway Authority, field evaluations were conducted on rail sections coated with various experimental materials. As a result, it was possible to compute annual cost per foot for the coatings that proved most successful. The one shown to be most economical is hot-dipped galvanizing at an annual cost of 10.5 cents per foot of rail. This figure is based on a service life of 10 years, using an interest rate of 4-percent compounded annually.

It was recommended that the Department undertake a program to remove, shop clean, galvanize, and re-erect all existing ungalvanized steel rails on the state highway system. As a result, galvanized guide rail is now required on all new construction and steps are being taken in conjunction with safety programs to remove all painted railing and replace it with the galvanized beam-type rails.

E. Photographic Condition Surveys

In 1960, The Bureau evaluated a commercially developed photographic method of recording pavement surface condition. This

consisted of taking bird's-eye-view, continuous-strip photographs with a truck-mounted camera at a traveling speed of approximately 25 mph. Photographs of seven New York State pavement surfaces were studied. It was concluded that the new method offered unique advantages of speed and objectivity in recording pavement surface features, and provided a permanent, complete record with a relatively high degree of resolution, readily lending itself to measurement of horizontal distances. The new method was recommended as a research or investigational tool where great lengths of pavement would be involved.

VI. BENEFITS TO THE DEPARTMENT AND SOME FUTURE PROSPECTS

A. Return on the Research Investment

It is difficult to place a dollar value on the benefits of research, particularly in such an organization as a Transportation Department, which is not in the strict sense "profit making." This is not to say that these benefits are not tangible, but only that they defy reasonable quantification. Furthermore, figures have not been available on individual project expenditures so that figuring benefits against costs by project is not possible. In the foregoing descriptions of accomplishments, it was possible to estimate savings for about one-third of those projects included. For a gross estimate of the benefit-cost ratio for research activity over the last 10 years, a comparison can be presented between the average yearly research expenditures and the annual savings produced by the results of those projects for which it was possible to reduce benefits to dollar values. Admittedly, this is a conservative figure because about two-thirds of the projects are not included; intuitively their benefits are easily recognized.

Total recurring benefits per year = $6,450,000

Average total research expenditures per year = $ 600,000

$$\frac{\text{Benefits}}{\text{Costs}} = \frac{\$6,450,000}{600,000} = 10.7$$

From this it is apparent that the Department has received a very favorable return on its research investment. Savings will undoubtedly continue to grow at an increased rate, not that the Engineering Research and Development Bureau is operating at its current level of personnel and funding.

B. Some Future Prospects

At this writing, the Engineering Research and Development Bureau is conducting an overall program of 60 research project investigations--some nearing completion and others of a long-term and

continuous nature. Another 15 are being developed in work plans. Because this program can be progressed only in proportion to available research facilities and personnel, the "needs and priorities" survey technique is an important new development in planning the engineering research program. This requires that rather than developing many small-scope investigations in response to specific, limited problems, broad research goals are developed for an entire program area--so far, in traffic and in structures. Needs studies can then be utilized to establish priorities, to give a measure of the level of effort required, and generally to guide the Bureau's resources into the most profitable and urgent research areas. This technique--along with annual review procedures to assure that changes in priority and urgency of researchable subjects will be detected--is expected to have an increasing influence on the Bureau's future development.

The Bureau's staff has also examined its responsibilities under the Department of Transportation's new orientation toward other transport modes than autos on highways. In January 1968, the Bureau published Engineering Research for Transportation, a prospectus for efficient exploration of other transportation technologies to meet the Department's new needs. This publication included a comprehensive survey of major current research trends and developments in rail, air, and mass transportation. Staff needs and an initial research program have also been outlined for the Department's administration.

Another new publication, designed as a companion to the present ten-year summary, also bears mention. A Transportation Engineering Research and Development Center for New York: A Prospectus focuses on how a research center of the proving-ground type might serve the needs of this and other New York State agencies, universities, and others in the Northeast. Facilities that might be included in such a center are listed, and benefits are enumerated.

Finally, steps are being taken to attack the "information explosion" on a more systematic basis. The Bureau's own Research Reports series, now amounting to nearly 100 major contributions to the engineering literature, are being distributed beyond this Department in increasing volume. Through correspondence with engineering research agencies sponsored by other units of government and by universities, a comprehensive program of document exchange is being inaugurated to bring the most up-to-date information available to our engineers. The services of the New York State Interlibrary Loan program are being fully utilized to obtain scarce periodicals and reports. As background to most new research projects. Bureau engineers are enriching their background reviews on new subjects with computerized file searches in the central data bank maintained by the Highway Research Information Service in Washington, D.C.